Quarterly Technical Summary

General Research

15 February 1969

Prepared under Electronic Systems Division Contract AF 19(628)-5167 by

Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Lexington, Massachusetts

The work reported in this document was performed at Lincoln Laboratory, a center for research operated by Massachusetts Institute of Technology, with the support of the U.S. Air Force under Contract AF 19(628)-5167.

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INTRODUCTION

This Quarterly Technical Summary covers the period from 1 November 1968 through 31 January 1969. It consolidates the reports of Division 2 (Data Systems), Division 3 (Radio Physics), Division 4 (Radar), Division 7 (Engineering), and Division 8 (Solid State) on the General Research Program at Lincoln Laboratory.

Accepted for the Air Force
Franklin C. Hudson
Chief, Lincoln Laboratory Office

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ENGINEERING – DIVISION 7

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DATA SYSTEMS
DIVISION 2

INTRODUCTION

This section of the report reviews progress during the period 1 November 1968 through 31 January 1969 for the General Research Program of Division 2. Separate progress reports on the Re-entry Systems Program, Graphics, STO-ARPA, ABMDA, and KMR describe other work in the Division. All the work of Groups 22 and 26 and some of the work of Groups 21, 23, 25, and 28 is therefore reported on separately.

F. C. Frick
Head, Division 2

V. A. Nedzel
Associate Head

DIVISION 2 REPORTS ON GENERAL RESEARCH

15 November 1968 through 15 February 1969

PUBLISHED REPORTS

Technical Note

TN No.				DDC and Hayden No.
1969-2	Pulsed Electron-Beam Heating	M. S. Cohen R. C. Johnston	10 January 1969	DDC* H-910

Journal Article†

JA No.			
3226	Hot Electron Transport in Al-Al_2O_3 Triodes Produced by Plasma Oxidation	E. E. Huber, Jr. F. L. Johnston, Jr. C. T. Kirk, Jr.	J. Appl. Phys. 39, 5104 (1968)

* * * * *

UNPUBLISHED REPORTS

Journal Article

JA No.			
3414	Reports on Recent Foreign Conferences	D. O. Smith	Accepted by J. Appl. Phys.

Meeting Speeches‡

MS No.			
2303A	Methods for Improving the Signal-to-Noise Ratio of Photon and Electron Beam Accessed Magnetic-Film Memory Systems	D. O. Smith	Magnetism and Magnetic Materials Conference, New York, 18-21 November 1968
2303D	Photon and Electron Beam Accessed Memory Systems	D. O. Smith	Seminar, University of Minnesota, 7 November 1968
2388	Determination of Domain Wall Profiles in Magnetic Films	K. J. Harte M. S. Cohen	Magnetism and Magnetic Materials Conference, New York, 18-21 November 1968
2503	Micromagnetics in Thin Films	K. J. Harte	Lecture Series, California Institute of Technology, 27-31 January 1969

* Not yet assigned.

† Reprints available.

‡ Titles of Meeting Speeches are listed for information only. No copies are available for distribution.

DIGITAL COMPUTERS
GROUP 23

I. CIRCUIT AND NEW MACHINE DEVELOPMENT

A. Semiconductor Processing

A set of master reticles for the 5 and 10 mW integrated gate chains was generated using the mask drawing program and sent to Philco-Ford for device fabrication. Seven weeks later packaged units were received for evaluation. From these samples and others with different resistivities, several points on the power dissipation – propagation delay curves for small geometry ECL gates will be obtained. The gate chains use small geometry, high frequency bipolar transistors and require two levels of metalization. No problems were encountered from the use of computer-generated masks. Eight more wafers are in various stages of processing.

A thermal evaluation chip has been produced from computer-drawn masks and will be used to study heat transfer for several different types of chip bonding schemes. The chip consists of a large number of small resistors, which are distributed evenly over the surface to act as heat sources, and a small number of large resistors, which can act as temperature sensors. Initial devices were mounted in a package with glass insulation between the chip and the cover. In this package with one watt dissipated evenly throughout the chip, the chip temperature rose to 139°C. With only one quadrant of the chip heated by 440 mW, the heated quadrant reached a temperature of 87°C while the most remote corner was 78°C. Further measurements will be made with heat-sunk packages, flip-chip contacts, and beam lead contacts.

Masks are being produced for three new integrated circuit elements. One is a 16 × 16 Read-Only-Memory array employing emitter-follower transistors at the crosspoints, the second is a simple ECL gate circuit employing the self-isolating diffusion process, and the third is a simple test chip for use in the interconnection work using chemically deposited metals.

B. Chip Interconnection

Good depositions of nickel on aluminum chip pads have been obtained using a modified commercial electroless nickel deposition process. An electroless gold plating can be applied to the nickel, if desired.

Construction of an alignment and bonding device for mounting chips to a metal substrate is nearing completion. Meanwhile, molded plastic facsimiles of chips are being used to determine how to apply a resin filler layer around the chips to support the chemically-deposited, photo-etched interconnection wiring.

Several approaches to the problem of selective application of insulating layers, to provide for vias to appropriate chip pads, are under consideration.

C. Interconnect Evaluation

The 4-bit adder and the 4-bit register logic arrays to be used in the microprocessor have been implemented using a proposed array of ECL gates on an LSI chip in order to study the

interconnection problem on the chip. A general scheme for distributing the connections to each gate was developed. Present results indicate that three laycrs of metalization will be adequate for fairly complicated logic networks.

D. Microprocessor

The design and layout of all printed circuit cards for thc microprocessor and its Read Only Memory is complete. Back panel wiring of the Read Only Memory has started. Back panel wiring of the microprocessor will begin in the near future.

E. Testing Terminal

The testing computer has been ordered and the system software is being developed. The small testing computer will provide direct typed output on a teletype and immediate graphic output on a storage scope. The graphic facilities will be limited to linear or logarithmic plots with automatic scaling and user-supplied labels.

The interface between the computer and the testing equipment is designed with flexibility in mind. It should be possible to change the testing equipment without a detailed knowledge of either the hardware or the software of the computer. All connections betwecn the testing equipment and the computer must be digital, and must be funneled through the test buffer, an array of 16 (expandable to 2^{16}) 16-bit registers. These registers are all double rank, so that it is possible to set individual bits and then transfer the entire bit pattern at once. In addition, the testing machine may catch the attention of the computer by setting a bit in one 16-bit interrupt register.

The software for this computer is not tied down to any particular testing equipment configuration. Instead, each bit of the test buffer may be addressed as an element of an array of truth values. A single command is also provided to transfer the test buffer bit pattern across the double rank register. Finally, a facility is provided for specifying the action to be taken when a particular bit in the interrupt register is set. It is hoped that these generalized input-output facilities will enable the users to write subprograms which will handle whatever test equipment they nced.

The test language will be interpreted, rather than compiled, to enable the users to develop test sequences step by step. The language will be built on top of a complete mathematical language based on the Rand Corporation's JOSS, to insure that the necessary facilities for manipulating data are available. A wide variety of conditional expressions will be available, to convert from the truth values of the test buffer to a numerical representation of the parameters of the device under test.

The testing language interpreter and as much of the testing computer operating system as possible will be written in a version of BCPL. Hopefully, this will eliminate much of the mystery which surrounds large, assembly language coded systems and thus make the system easier to modify.

II. MAGNETIC FILM ENGINEERING

A. Large Capacity Memory

1. LCM Digit Lines

We have demonstrated the importance of uniform spacing between word and digit lines in order to minimize undesired coupling due to capacitive imbalance. A thin layer of high dielectric oil between the flexible digit line and rigid word substrate reduces imbalance by holding the digit line to the substrate and filling air spaces at positions where particles of dirt create spacing irregularities. The use of a rigid digit substrate which would eliminate local spacing irregularities is being examined.

2. Digit Line Scribing

Three digit line patterns of the LCM II configuration have been generated by scribing copper clad plastic. Each set comprised 200 lines, 0.006-inch wide on 0.010-inch centers, approximately 52 inches long. Pad patterns were connected to the line sets by simultaneously soldering all 200 joints using RF induction heating. Edge definition was excellent and there were no opens but insufficient depth of cut and tool skip caused some shorts. Tool skip is due to bumps on the electroplated copper which would also cause nonuniform spacing as described above.

A variation on the flat, back-and-forth scribing method has shown great promise. The copper clad plastic is pulled down against a round vacuum chuck mounted in a lathe; then the lines are cut in the form of a screw thread using three to five passes of a diamond stylus mounted in the lathe tool post. Several 56-inch-long line sets have been made this way, and are as good as the linearly scribed lines. The lathe method has the advantages of being simple and approximately ten times faster than the linear method.

3. Word Line Scribing

Tool wear factors for the scribing of copper on glass are understood and tool loading is no longer critical. Remaining problems are those of accurate tool indexing and improved control of depth of cut.

4. Word Decoding Matrix

Mechanical models of diode matrix "sticks," consisting of silicon chips bonded to copper bus lines, have been produced by soldering silicon wafers to copper plates. This sandwich is then sawed up to make the copper bus-diode chip "stick" as well as to electrically isolate the diodes from each other. When details of the process are worked out, commercial diodes in wafer form will be used to evaluate effects of bonding and mechanical working on electrical characteristics.

5. Digit Line Flux Closure

Experiments with three-sided digit keepers have verified the theory that an overall improvement of a factor of six in signal can be obtained for fixed word-line width and digit current. Carbonyl iron in a plastic binder and plated permalloy alone or in combination have been used successfully as keeper materials.

6. Magnetic Film Plating

Films nearly pinhole free and of good adhesion but marginal magnetic properties have been plated on polysulfane plastic substrates. Copper conductors 0.002-cm thick, almost defect free, and smooth enough to use as magnetic film substrates have been plated.

III. SYSTEM PROGRAMMING

A. APEX Magnetic Tape Facility

Magnetic tape is now fully operational in APEX. A public routine, which includes a tape package designed for general use, controls tape manipulation via typed commands. This package produces the calls which control tape motion and fields any errors or conditions generated by the tape or the tape hardware. The Mark 5 assembler uses the tape package for reading and writing assembly language directives.

B. Circuit Simulation

The sparse matrix package described in the last Quarterly Technical Summary* has been incorporated into programs for analyzing a variety of digital circuits. In almost all cases the sparse matrix techniques reduced analysis time significantly. For example, the times required to calculate the transfer functions of a differential amplifier (containing two transistors) and a two input NOR gate (containing five transistors) were reduced as follows:

Circuit	Speed-Up Factor (approx.)
differential amplifier	2
NOR gate	5

In general, the use of sparse matrix techniques tends to make analysis time proportional to N, instead of N^3, where N denotes some measure of problem size. Thus, even larger speed-up factors can be expected for multiple gate circuits.

IV. COMPUTER SYSTEMS

A. Display

Four additional Tektronix storage CRT units are being installed in the TX-2 display system. They should reduce substantially the TX-2 load due to displays.

The storage CRTs have a much slower writing rate than the normal type CRT. This is not a problem for the conic generator since it is capable of operating at a wide range of speeds; however, the commercially made character generator does not have a variable speed capability. A character generator is being designed utilizing the techniques and components developed for the conic generator. This character generator will have a variable writing rate and should produce more pleasing characters.

B. Page Address Memory

A 1024 word, 16-bit high-speed flip flop memory using Motorola MECL memory elements is under construction. It will be used as a Page Address Memory for TX-2. Read or write times will be under 50 ns.

* General Research Quarterly Technical Summary, Lincoln Laboratory, M.I.T. (15 November 1968), DDC 680221.

COMPUTER COMPONENTS
GROUP 24

I. PERMALLOY FILMS

A. Analysis of Lorentz Micrographs

Further theoretical work has been carried out on "inversion" procedures[1] which yield domain wall profiles from electron intensity distributions deduced from Lorentz micrographs. This work demonstrated the necessity of careful arithmetic calculations of a complicated weighting-function for the semi-classical analysis; the full classical analysis was much simpler. Although artificial cases which require the semi-classical analysis for accuracy could be constructed, the experimental data could be adequately inverted using the classical analysis.

The results show that in NiFe films the domain wall width decreases from 1,500 to 500 Å as the film thickness increases from 100 to 400 Å. It is difficult to obtain meaningful results for thicker films due to nonmagnetic electron-scattering in the films; such scattering effects have not been adequately appreciated by previous workers.

B. Anisotropy Spectrum of Magnetic Films

Anisotropic electrical resistivity[2] accompanying the magnetic anisotropy has been observed in 100% Ni and 70% Ni-30% Fe films in a field of 3 kG. The effect is about 1 part in 10^4 and of opposite sign for these two compositions. This fact, coupled with the absence of anisotropic resistivity in 83% Ni-17% Fe (zero-magnetostriction) Permalloy, indicates a strain-magnetostriction mechanism as the origin of the associated uniaxial anisotropy process.

In addition to clarifying the physical mechanism involved, this method separates out a single process, overcoming an inherent difficulty in earlier hard-axis annealing studies.[3] At 200°C, the observed relaxation time is about 10^3 sec for both positive and negative magnetostriction. Studies are continuing to obtain the activation energy and frequency factor for this process.

II. PEBA MEMORY SYSTEM

A. Electron-Electron Pumping

It has previously been suggested that a single bit be activated by thermally pumping electrons from the ground state to a nearby intermediate state. Read-out then occurs by optical excitation to an upper level. Significant improvement in signal-to-noise ratio would occur if, instead of thermal pumping, electrons were pumped directly by electron-electron interaction to an optically active excited state (cathodoluminescence). High efficiency of infrared cathodoluminescence has been reported for rare-earth ions in Y_2O_3 (Ref. 4), but no data are available for the iron garnets. Furthermore, the lifetime of the relevant excited states is commonly measured as ~100 μsec, too long for the desired 1-μsec memory cycle time. However, recent theoretical work[5] shows that much faster decay will occur in systems with a high density of excited atoms. Experiments are under way to obtain the information needed for the memory application.

B. Pulsed Electron-Beam Heating

An experimental electron-optical system has been constructed to study the effect of variations of the heat-source diameter on the rise time and ultimate temperature of an electron-bombarded surface. The theoretical results of Smith[6] were generally found to be valid, i.e., the rise time depended on the square of the spot diameter and the predicted ultimate temperatures were found. A full report is given in Technical Note 1969-2 (Ref. 7).

C. Binary Detection of Signal Photons

The detection scheme for determining whether a one or a zero is being read out magneto-optically from a memory bit consists of a photon receiver making an optimum decision that either signal photons are present (one) or are not present (zero). The decision is made on the basis of the input signals to the receiver which may consist of noise (both photon and electrical) alone (zero) or of a signal (photon) plus noise (photon and electrical) (one). The criterion on which the decision of the receiver is based is the minimization of the probability of making an error in this decision.

For the case in which the a priori probability for the occurrence of a one or a zero is equally likely, the mean time between failures (errors) T_{MTBF} in terms of the receiver and memory characteristics is given by the relations

$$\frac{1}{4}\,\eta_s\,\langle\Delta I_r\rangle_S\,T_{RS}/F_{rcvr} \overset{(\geq)}{=} \ln(T_{MTBF}/T_{RC}) \qquad (1)$$

and

$$2B_{rcvr}T_{RS} = N_S \gtrsim 10 \quad . \qquad (2)$$

Here η_s is the quantum efficiency of the photo-electric detector; $\langle\Delta I_r\rangle_S$ is the average signal photon flux; T_{RS} is the read sample time; F_{rcvr} is the receiver noise figure defined as the ratio of the total output noise power of the receiver per unit bandwidth to the input noise power per unit bandwidth engendered by the signal photons; T_{RC} is average read cycle time (time between successive reads); B_{rcvr} is the bandwidth of the receiver; and N_S is the number of independent samples of the input signal data that can be obtained in the time T_{RS}. For Eq. (1) to hold in the case of a Poisson distribution of the signal photon flux, N_S must be approximately 10 or greater.

If for example $\eta_s = 0.8$, $T_{RS} = 1\,\mu$sec, $T_{RC} = 3.16\,\mu$sec and T_{MTBF} is required to be 10^9 yrs (or 3.16×10^{16} sec), then the relation between the signal photon flux and receiver noise figure is given by the expression

$$\langle\Delta I_r\rangle_S \overset{(\geq)}{=} 250\,F_{rcvr}\ \text{photon}/\mu\text{sec}$$

while the receiver bandwidth is required to be

$$B_{rcvr} \gtrsim 5\ \text{MHz} \quad .$$

Since $F_{rcvr} \geq 2$ by definition, then

$$\langle\Delta I_r\rangle \geq 500\ \text{photon}/\mu\text{sec} \quad .$$

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3. D. O. Smith, G. P. Weiss, and K. J. Harte, J. Appl. Phys. 37, 1464 (1966).
4. R. A. Buchanan, K. A. Wickersheim, J. L. Weaver, and E. E. Anderson, J. Appl. Phys. 39, 4342 (1968).
5. V. Ernst and P. Stehle, Phys. Rev. (to be published).
6. D. O. Smith, IEEE Trans. Magnetics MAG-3, 433 (1967).
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PSYCHOLOGY
GROUP 25

I. PROVISIONS FOR MAN-MACHINE INTERACTION ON THE IBM 360/67

A. Mediator

The Mediator is an interrelated collection of routines that supplement CMS (the Cambridge Monitor System) by providing the services needed to support a coherent library of programs. The redesigned Mediator on which a subcontractor has been working appears to be complete. Its operation under simple conditions has been demonstrated, and acceptance tests under more complicated, realistic conditions are being performed. To this end, some of the Reckoner programs have been put into operation. They include the basic programs for output to and input from the terminal, the basic program that accepts a command from the terminal, a program that runs through a file of characters executing the commands it finds there, programs that create and join files of characters, and programs that allow the user to inquire about the state of his files and of the system. This set of programs permits a realistic shakedown of the correctness of the Mediator's behavior under complicated conditions, and of its ability to degrade gracefully when the demands for space are heavy enough so that files must move back and forth from the disk. No serious problems have been discovered.

B. Reckoner

The Reckoner is a coherent set of programs that is being constructed on the foundation of the Mediator. It is like the present TX-2 Reckoner, but without CRT displays for the time being. Most of the programs will be written in Fortran and will make their service requests to the Mediator by calling for machine-language subroutines known as "studs." A set of about 20 studs – some essential, and some just conveniences to a Fortran programmer – have been coded and tested.

The initial Reckoner will consist of about 25 programs, in addition to those mentioned in the section above. Detailed specifications describing each program from the user's point of view have been written, reviewed by a standards committee, and revised. Most of the coding has been done, and a few programs have been checked out. Further checkout has been postponed briefly so as not to interfere with the acceptance tests of the Mediator. The assumption is that with the studs and the Mediator available, the initial Reckoner library will be completed very rapidly.

C. Editor

A new version of the Editor System, revised to follow the conventions of coherent programming and to rest on the Mediator, has been delivered by the subcontractor.

II. PROVISIONS FOR MAN-MACHINE INTERACTION ON TX-2

A. APEX

Magnetic tape facilities are now available in the APEX time-sharing system on the TX-2 computer. In addition to the basic supervisor calls for operating the tape units, a package of

public programs has been written to allow direct use of tape services from a console. Another package of public programs simplifies the use of tape from arbitrary user programs by handling the many possible error situations that can occur.

A number of difficulties that affected the performance of the system in special situations have been analyzed and corrected. Among them was a design problem that caused excessive overhead whenever a structural display file contained many small character blocks. In one bad case as much as 60 percent of the computer's capacity was used in maintaining the display. Small changes to both hardware and system software reduced the figure to 12 percent. The improvement in this particular case was dramatic, but since this type of display is not widely used, the effect on overall performance is much more modest.

III. HUMAN FACTORS IN ON-LINE COMPUTATION

The effect of response delays on solving problems with the help of an on-line computing service is being studied experimentally. Work continues on the experiment in which the average delay in the machine's response is 1, 4, 16, or 64 sec, but individual delays vary at random. It was decided that the experiment was worth expanding: each of the four subjects would solve 48 problems instead of 16. When the expanded experiment was nearly complete, the TX-2 computer entered a period of comparative unreliability. After a considerable amount of data had been lost (nearly a quarter of the problems were spoiled and new ones had to be devised), experimentation was suspended for several weeks. Apparently this sort of work is not feasible without a higher level of reliability than is demanded by programmers and other users in practice. The reliability of the machine now seems to have settled down again, and regular experimental sessions have been resumed.

COMPUTER SYSTEMS
GROUP 28

I. COMPUTER CENTER DEVELOPMENT

Two major pieces of equipment were installed during the past quarter. A 2314 Disk Storage Facility was added to the main computer system in December. This unit consists of a cluster of eight separately addressable drives, each of which accesses a removable disk pack providing storage for up to twenty-nine million characters. Unlike the two existing 2314's which are attached exclusively to one or the other main processor, respectively, this new unit may be switched to either or both main processors. Its primary role will be to add much needed secondary storage for the time-sharing system. Because its switching capability permits access from both processors, it will also provide shared file storage whenever the OS/360 Batch Monitor is operated in parallel.

The second major device to be installed during the quarter is a Stromberg-Carlson 4060 CRT Plotter. Although it is not yet ready to start a parallel acceptance test with the older Model 4020, early results look quite promising. Besides increased plotting resolution and improved vector capability, the 4060 is expected to provide a number of very welcome operational features. These include an easier to handle and more reliable hard copy output process and the use of less expensive consumable supplies. A final acceptance test should begin early next quarter after a few weeks of operator and programmer training.

The extension of the computer room is nearly completed. Several badly crowded system components, which were developing problems of overheating, have been moved into open areas where the air conditioning can properly handle the heat load. The tape library has been moved into a separate fire-proof area, and the entire facility is now protected by an automatic fire detection and sprinkler system. Work is in progress to complete an improved and expanded user facilities area.

The popularity of cathode ray display devices on the time-sharing system continues to grow as the software support increases. Most of the work involves the IBM 2250 Graphical Display Unit. Early applications have been to display graphical data which would normally have been produced offline. The immediate presentation of results permits both selection and modification of the final hard copy output. This means a substantial savings in turn-around time as well as the number of computer runs required to process a quantity of data.

Work is also in progress to support the small IBM 2260 alphanumeric display device. This unit does not provide a graphic capability, but may be used for such applications as the rapid scanning of alphanumeric information or as an operations control console. Initially, this unit will be used only as a display. After this capability is established, the keyboard facility will be implemented and the 2260 will be able to function just like the standard 2741 typewriter-like terminals. Since the 2260 operates through a separate control unit, this would increase the capacity of the system from the present hardware limit of 32 to 36.

II. LISTAR (Lincoln Information Storage and Associative Retrieval System)

Since the last report, work has proceeded on extending LISTAR functions. Programs for making references across file blocks have been revised to permit greater flexibility in handling associations between entries. A new command language has been written which minimizes the dialogue between the system and the user and which facilitates the addition of new system commands. Programs have been written which can be called for adding new entries into a file. The command language programs to permit a user to add entries from the terminal or to execute a bulk input from tape or disk are now being prepared. Similar programs are in process to permit the implementation of commands for changing values in entries and for deleting parts or all of a file.

RADIO PHYSICS
DIVISION 3

INTRODUCTION

This section summarizes the General Research efforts of Division 3 for the period 1 November 1968 through 31 January 1969. A substantial portion of the Division's activities is devoted to the PRESS Program, reports for which appear in the Semiannual Technical Summary and the Quarterly Letter Report to ARPA.

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Head, Division 3

M. A. Herlin
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DIVISION 3 REPORTS ON GENERAL RESEARCH

15 November 1968 through 15 February 1969

PUBLISHED REPORTS

Technical Note

TN No.			
1968-22	Post-Real-Time Radiometric Special Line Processing at Haystack	J. A. Ball	18 June 1968

Journal Article*

JA No.			
3373	Interstellar Sulfur Hydride: A Search for the 111-Megahertz Lines	M. L. Meeks M. A. Gordon M. M. Litvak	Science 163, 173 (1969)

* Reprints available.

SURVEILLANCE TECHNIQUES
GROUP 31

I. SUMMARY

Group 31 conducts the research program of Lincoln Laboratory's Millstone and Haystack radio/radar research facilities.

An evaluation of the Millstone antenna tracking system has continued in preparation for the Millstone ABMDA radar propagation program. Reports on this program will henceforth be included in the Quarterly Letters and Semiannual Reports on the Laboratory's total ABMDA program. Thomson scatter observations have measured horizontal velocity drifts in the ionosphere in accordance with a theory of driving action by the neutral atmosphere.

Dual polarization radar studies of the moon are well under way at Haystack in a program supported by NASA. Spectral line radiometric studies at Haystack have now been extended up to 23 GHz. Observations have confirmed the recently detected 23-GHz microwave emission from ammonia molecules in the direction of the galactic center. Planetary radar work this quarter has continued to accumulate data to establish more precisely the orbits of the planets in support of the Fourth Test of Relativity experiment.

II. SPACE SURVEILLANCE TECHNIQUES

In this program, a study of radio aurora is being made to determine their effect on radar observations through an auroral event. During analyses of 1968 auroral data, an apparent increase in received noise level by as much as a factor of five was observed when very strong auroral echoes (several hundred thousand degrees antenna temperature) were received. This might be interpreted as radio emission from the aurora. Subsequent study of receiving and data processing equipment has, however, shown the possibility of erroneous values of receiver noise when very strong echo signals are received. Thus, it is still uncertain whether radio emission from aurora does occur at frequencies above VLF. Steps are being taken to eliminate possible errors in noise level calibration in future auroral measurements.

In the new series of auroral backscatter measurements, alternate 500- and 10-μsec pulses will be transmitted to provide good resolution nearly simultaneously in both the doppler and range of auroral echoes. A computer program for the data taking phase of this work has been completed and is ready for checkout.

III. PLANETARY RADAR

A. Lunar Studies

The dual-channel maser receiver was completed and on the air on 21 October, on schedule. The system performance is good, with a system temperature (lunar mode) of 75°K in the "ortho" (expected polarization) channel and 90°K in the "thru" channel. The first few subarea maps have been produced from observations made in November 1968. The moon is divided for the purpose of this program into a series of quasi-range/doppler areas, which we term "ZAC" areas, and

which are far more compatible with the geometry of the range/doppler techniques than the latitude/longitude divisions of the Lunar Aeronautical Charts published by the Air Force. The visible hemisphere of the moon has been divided into 227 ZAC areas. We have completed satisfactory measurements of 30 of them in the 21 October – 28 November radar observing period, and 65 more of them during the 15 January – 6 February period. Separate measurements of both the polarized and depolarized radar returns are recorded simultaneously and separate maps will be produced. Pulse widths of 3 to 13 μsec can be employed depending on the angular distance on the moon from the subradar point to the area being observed, and hence on the delay-resolution that is required for our intended 2.5-km surface resolution. Five such pairs of maps have been produced so far.

Many regions of enhanced and diffuse depolarized return are evident, several of which have no apparent origin on optical photographs from earth-based telescopes. We intend to compare the more striking of these regions with the lunar Orbiter photographs, which are available for most of the visible face of the moon, to see if these regions are associated with regions of increased small-scale roughness.

This work* is reported in more detail in the present series of Lincoln Laboratory Quarterly Progress Reports entitled "Radar Studies of the Moon."

B. Planetary Observations

Planetary radar operations resumed 25 October and continued through 26 November 1968 following an extensive upgrading period during the previous quarter. Mercury and Venus ranging observations during this period were intended to establish more precisely the orbits of those planets, partially in support of the Fourth Test of Relativity experiment. A series of radar cross section measurements on Venus was initiated to obtain as complete coverage as possible for a complete axial rotation of the planet.

A second series of planetary operations started on 15 January 1969 and continued beyond 31 January. Finer resolution measurements of Venus in ranging and power spectra were also initiated as a prelude to a period of extensive coverage centered about Venus' closest approach in April.

C. System Performance

The radar maser receiver continued to show the improved temperature performance achieved during the upgrading period. The primary or left-circularly polarized channel consistently achieved a 43°K system temperature at a 45° elevation angle. The maser does have a problem with gain variation as a function of elevation angle that does not hurt radar operations but is detrimental to continuum radiometric observations. The liquid helium hold time was discovered to depend upon the inclination of the dewar and hence the antenna elevation angle. The effective hold time fortunately is longest (12 to 15 hours under optimum conditions) when the antenna is elevated near 45°. Both of these elevation sensitive effects are apparently the result of mechanical deflections in the maser header in the dewar assembly and will be investigated at a later date.

Two new VA-949AM transmitter klystrons were installed in December. The tubes removed had been limited to 250 kW because of an apparent internal arc in one of them. The new klystrons

* Partially supported by the National Aeronautics and Space Administration.

were operated at over 300 kW at first, but one tube has now developed symptoms of a DC arc problem, particularly in the pulse mode of operation used by lunar radar operations. The problem may require that this klystron also be changed. If this problem is resolved satisfactorily, a 350-kW transmitter should be available for operations during the spring.

IV. THOMSON SCATTER

Observations successfully completed during the reporting period include five conducted at UHF to determine ionospheric temperatures and densities over a 24-hour period, and four for the determination of the vertical drift velocity over a complete day. In addition, some observations have been made at L-band in an attempt to determine horizontal drifts in the ionosphere. In these measurements, the antenna is tilted to a 15° elevation angle and 1 msec pulses are employed. By directing the antenna alternately north and west, both the speed and direction can be determined. A preliminary analysis of the data indicates that for only about 6 hours in the day is the echo intensity high enough to yield useful velocity information. However, during this period, a horizontal drift seems to be present having the direction expected if the driving mechanism is the motion of the neutral atmosphere brought about by the diurnal cycle of cooling and heating.

V. RADIOMETRIC TECHNIQUES

A. Instrumentation

Additions to the radiometer instrumentation for the 2 December – 31 January observing period included installation of a 22- to 24-GHz spectral line radiometer and modifications for a 1650-MHz switched-frequency interferometer experiment. After the Radiometer Box was removed from the antenna in January, a 23-GHz parametric amplifier was added to the 22- to 24-GHz radiometer and an 8-GHz horn feed was installed.

The 22- to 24-GHz radiometer, borrowed from NASA/ERC,* uses a crystal mixer with a single sideband noise temperature near 4000°K. Local oscillator power is supplied by a klystron phase-locked to a harmonic of the L-band local oscillator. Spectral analysis of the IF signal is performed by the Haystack autocorrelator system. Its output is a difference spectrum between the main antenna beam and the off-axis beam or a comparison load. The parametric amplifier, built by RLE and recently installed ahead of the mixer, should reduce the system noise temperature to about 400°K when the Radiometer Box is replaced on the antenna.

For the long baseline interferometer experiment, equipment was installed to switch the L-band parametric amplifier and the first and second local oscillators in nine steps over the 100-MHz band, centered at 1650 MHz, at a rate of five steps per second. A high-speed interface to the CDC 3300 computer was constructed to record the interferometer data using one of the computer's tape drives.

The 8-GHz horn feed should provide a 45 percent improvement in antenna efficiency over the Clavin feed used on the R-Box until now. The Clavin feed may be used as a comparison feed for beam-switched radiometry. Installation of the feed required moderate repackaging of the 8-GHz radiometer.

* Electronics Research Center, Cambridge, Mass.

B. Observing Program

1. Pointing Corrections for the Millstone Antenna

The pointing characteristics of the Millstone 84-foot antenna with the Cassegrainian feed system are being accurately measured in preparation for its use as a precise instrumentation radar in the ABMDA Propagation Study. The initial measurements were made by using the Univac 490 computer at Haystack to scan radio sources and determine the pointing angles where maximum power was received. Over 100 points were obtained in this way. A linear elevation bias was detected as a function of elevation angle which is probably attributable to the sagging of the subreflector. The rms scatter in the elevation error was about 0.008° after the linear error was removed. Wideband phase detectors have since been installed on the monopulse error channels which give a direct electrical measure of the angular tracking error. Since the angular sensitivity is now about 3 minutes of arc when tracking Cas A under computer control, the granularity in the tracking due to the encoder quantization (least significant bit = 40 seconds) can easily be seen. The problems and cost of increasing the accuracy of encoding by two more binary bits are being evaluated as a result of these tests.

2. Spectral Line Observations

Observations with Haystack during the first week in January have confirmed the detection of 1.25-cm microwave emission from ammonia molecules in the direction of the galactic center. This emission was discovered by radio astronomers at the University of California and a report published in Physical Review Letters, 16 December 1968. The Haystack work was performed in cooperation with the NASA Electronics Research Center (Cambridge, Massachusetts); their staff provided the 23-GHz radiometer and assisted in the observations. At 23 GHz, the Haystack antenna has an efficiency of 20 percent, based on observations of the planet Jupiter, and the half-power beamwidth is 1.5 arc minutes. With this small beam, we were able to show that the ammonia spectral-line source is extended in angular size and is roughly 3 arc minutes across.

Jointly with radio astronomers from Harvard, we observed the bright 18-cm OH emission from two radio sources which were occulted or nearly occulted by the sun on 21 and 22 December. Radio astronomers at the Naval Research Laboratory (NRL) had reported a frequency shift in the 21-cm hydrogen absorption line in the direction of the Crab Nebula when the sun passed near this source in 1967 and 1968. The effect reported by NRL is not predicted by existing theories, and we wished to make an independent search for such a frequency shift. Our data fail to show any frequency shift, and our uncertainty limits are 50 Hz compared with the 150-Hz frequency shift reported by NRL. Furthermore, we observed sources (designated W28 and G5.9-0.4) nearer the limb of the sun than the Crab Nebula at its closest approach.

RADAR
DIVISION 4

INTRODUCTION

The Radar Division conducts a General Research program to develop new radar components and techniques which appear useful for future systems. The activities in this program for the period 1 November 1968 through 31 January 1969 consisted of the development of computer-aided microwave diode devices, millimeter radar techniques and precision timing components. Separate reports are issued on the RDT, PRESS, RSP and MTI Radar programs.

H. G. Weiss
Head, Division 4

DIVISION 4 REPORTS ON GENERAL RESEARCH

15 November 1968 through 15 February 1969

PUBLISHED REPORTS

Journal Articles*

JA No.			
3233	The Feasibility of Locating Waveguide Arcs by Sound Ranging	A. A. L. Browne	IEEE Trans. Microwave Theory Tech. MTT-16, 894 (1968)
3356	A Millimeter-Wave Lunar Radar	J. J. G. McCue E. A. Crocker	Microwave J. 11, 59 (1968)

* * * * *

UNPUBLISHED REPORTS

Journal Article

JA No.			
3342	X-Band Gas-Tube Pulsed Attenuator for Maser Protection	A. A. L. Browne C. E. Muehe	Accepted by IEEE Trans. Electron Devices

* Reprints available.

MICROWAVE COMPONENTS
GROUP 46

I. INTRODUCTION

Group 46 contributes to the radar program through direct participation in specific projects, and through a program of general research which is closely related to the microwave needs of the Laboratory. Contributions are made through the study of the problems of solid state diode-using devices, the development of techniques for computer design of microwave devices, studies of very high gain antennas and antenna feeds, operation of a high power microwave laboratory, and participation in a millimeter wavelength program.

II. DIODE-USING DEVICES

A. Diode Measurements

The resistive disks ordered for the 30-inch, radial-line cavity have arrived. The coaxial coupling into the radial line cavity was modified to take one of the disks near the inner surface of the cavity.

Radial cavity measurements with the resistive disk and a solid-copper dummy diode indicate that the expected reduction in detuning errors has been achieved. Present work is aimed at reduction of higher order resonances introduced by imperfect centering of the dummy diode.

B. Power Combiners

The 15-diode, coaxial power combining doubler was assembled and tested at low power. The specially constructed columns of five diodes and cooling fins integrated in a single unit simplified the assembly work, and gave no physical or electrical problems.

The new lower loss diplexer and tuners improved the doubling efficiency to 75 percent (it had been 57 percent with the previous power combiner, diplexer and tuners), but the maximum power applied was only 50 watts, because the high power TWT amplifier failed. It is hoped that an inexpensive substitute generator can be located.

C. Low Noise Balanced Diode Mixers

The preliminary S-band balanced diode mixer which had a conversion loss of approximately 3 dB (including 1.8 dB of filter and circuit loss) has not yet been tested for noise figure. There was a problem with the noise figure measuring equipment which required repairs by the manufacturer. The measurements will be made when the equipment is returned.

In the meantime, a balanced diode mixer has been designed and built for use at X-band. Conversion loss measurements are being initiated. Some additional Schottky Barrier diodes have also been purchased and are now being tested.

Finally, a newly designed mixer for use at S-band and X-band has been fabricated. This mixer places the diodes in a shunt arrangement rather than in the standard series configuration. It is hoped that this will result in even more efficient mixing.

III. COMPUTER-AIDED DESIGN OF MICROWAVE CIRCUITS

A. Automatic Analysis of Microwave Circuits

The general purpose automatic microwave circuit analysis program (general circuit parameters or GCP) is being debugged and a user's manual is being prepared. The program now handles frequency analysis of linear two-port cascades with tree-like branches (no closed loops) and has been given an element-tuning capability.

It is intended that this version of GCP be finalized and released to other groups in the Laboratory before work is begun on a more sophisticated version.

IV. MILLIMETER WAVELENGTH PROGRAM

The multipliers which convert from 5 MHz to 35 GHz which failed late last summer have been repaired by Sylvania and retuned to give a good spectrum. Calibration and receiver drift problems are now being dealt with in preparation for a final set of observations which will be made when the phase of the moon and the weather are favorable.

The writing of the final report on this program has commenced.

V. MISCELLANEOUS

A small effort is being undertaken to study and define the problem areas associated with the use of atomic frequency standards in connection with precision time interval measurements. Initially, two Hewlett-Packard cesium beam clocks are being procured, and other necessary electronic equipment is being assembled.

ENGINEERING
DIVISION 7

INTRODUCTION

The Engineering Division supports the General Research Program in three principal areas: the upgrading of facilities at Haystack and Millstone Hill, the design and fabrication of equipment used in solid state research, and research and development of microelectronic circuitry at our new Integrated Circuit Facility.

In this winter quarter from 1 November 1968 to 31 January 1969, improvements at Haystack have included the replacement of the air conditioner and the development of a new feed horn assembly in the radiometer box. In addition, systems tests are being conducted on the improved closed cycle cryogenic refrigerator. At Millstone designs have been produced for a new frequency-selective subreflector and monopulse feed, while at the nearby Firepond site, the assembly and alignment of the mirror mounts as well as the servo control systems and monitoring devices for the CO_2 laser are nearing completion.

Here at the Laboratory, solid state research has been supported during the quarter by redesign of pressure anvils to improve the efficiency of the high pressure tetrahedral device. And in the Integrated Circuit Facility, new and refined techniques for applying metallurgical materials in ever higher resolutions are being exploited. New assembly concepts using beam-lead substrates and RF sputter-etching techniques are examples of these developments. A parallel effort is concerned with the actual layout of circuits by computer-aided means.

J. F. Hutzenlaub
Head, Division 7

DIVISION 7 REPORTS ON GENERAL RESEARCH

15 November 1968 through 15 February 1969

PUBLISHED REPORTS

Technical Note

TN No.				DDC and Hayden No.
1968-25	Semiconductor Processing Applied to Integrated Circuit Fabrication	R. A. Cohen R. W. Mountain	26 August 1968	DDC 679560 H-906

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UNPUBLISHED REPORTS

Journal Articles

JA No.			
3393	Silicon Dioxide Thermally Grown in a Silicon Nitride Ambient	R. A. Cohen R. Wheeler*	Accepted by J. Electrochem. Soc.
3406	Method for Fabricating High Frequency Surface Wave Transducers	H. I. Smith	Accepted by Rev. Sci. Instr.

Meeting Speech†

MS No.			
2357	A New Fabrication Method Using Beam Leaded Substrates	R. E. McMahon R. A. Cohen	NEREM, Boston, 6-8 November 1968

* Author not at Lincoln Laboratory.

† Title of Meeting Speech is listed for information only. No copies are available for distribution.

MECHANICAL ENGINEERING
GROUP 71

I. HAYSTACK

A. Radiometer Box

Due to continued service problems and a noise level uncomfortable to operating personnel, the 400-cycle Garrett 2.5-ton air conditioner has been replaced on the radiometer box with an adapted Cox 5-ton fan-coil unit which utilizes chilled water from the existing system. In addition, new ducting was installed inside the box to the front cylindrical section to cool equipment and increase personnel comfort.

The radiometer box wall between the main area and the front section was modified to accommodate the mounting of the 8-foot long 7.75-GHz multimode horn assembly in an off-axis position.

Designs have been finalized and fabrication is progressing on a 23-GHz dual-feed assembly. The main horn, an internally finned type, feeds through a circular polarizer and an orthogonal mode transducer to WR-42 waveguide. This horn together with a comparison horn is mounted on-axis with their center lines offset 11 inches.

B. Cryogenics

Prior to undertaking a cool-down of the simulated maser package in the closed cycle refrigerator, a blank header was installed and the unit was cooled down to 3.8°K in approximately 3 hours. The refrigerator maintained a temperature of 4.2° with an electrical heat load of 0.75 watt.

The simulated header was leak-checked in an independent vacuum fixture and found to have vacuum leaks at the electrical connectors. This condition has been remedied and the unit is now being readied for system cool-down.

Liquid helium boil-off measurements have been performed on a nitrogen shielded dual maser dewar. With no external heat leak into the dewar, it held helium for 86 hours in the vertical position and for 66 hours at 45° to the horizontal position. Inserting a 37.5-pound load into the bottom of the dewar, simulating a dual maser, resulted in a hold time of 51 hours in the vertical position and 37 hours when positioned at 45° to the horizontal.

II. MILLSTONE

Preliminary studies have been made to define the physical limitations and the mechanical interface for a new frequency-selective subreflector and UHF monopulse feed assembly to replace the existing subreflector of the 84-foot diameter Millstone tracker. The present apex enclosure and subreflector hoisting system will be retained to enable possible subreflector interchange.

III. SOLID STATE RESEARCH (High Pressure Techniques)

Our purpose this quarter was to improve the capability of the existing high pressure equipment.

A tetrahedral device, developed several years ago, eonsists essentially of four piston elements with blunt, three-sided, pyramidal ends and equilateral triangular faces which bound a tetrahedral volume.

Each piston is able to develop a load of 2000 tons which is intensified and translated to pressures up to 100,000 atmospheres, depending on the dimensions of the triangular faees; smaller face areas yield greater pressures than larger face areas. This immcdiately ereates thc problem of having to continuously change anvils to meet volumc and pressure requirements, which is impractieal and is not economically feasible.

A compromise was found in the use of anvils with equilateral triangular faces 2.2 inches on a side, since 80 percent of all experiments with the apparatus are performed at less than 70,000 atmospheres. Higher pressures, when needed, are obtained by utilizing intensificrs which are an integral part of the pyrophyllite envelope and consist of four triangular hardened steel plates. The choice of intensifier size determines the efficiency of the unit.

Comparative pressure data of the unit with and without intensifiers arc:

Bi I-II-transition (25 kb) – 130 and 450 tons, respectively
Ba-transition (60 kb) – 550 and 1350 tons, respeetively

Both points are accepted calibration standards based on the polymorphic pressure transition of bismuth and barium.

IV. CO_2 LASER RADAR

The three mirror mounts and their supporting pedestals havc beon eomplctely assembled and have been installed at thc Firepond site on Millstone Hill. Alignmcnt of the two fixed mirrors and servo testing of the tracking mount are now in progress.

All of the parts of the television camera mount have been fabricated and the mount is being assembled. A system of stops has been designed for the lowcr fixed mirror mount which will allow for auto-eollimation without the necessity of realigning the mirror system after eaeh such operation. The parts for this stop system are now being fabrieated.

The two beam expanders, the flat mirrors and their supports have been completed and are now being aligned at the site.

Design and erection of equipment enclosures which will insure the safc operation of the various lasers and still allow access, with proper interlocking, for scrvice and adjustment will begin next quarter.

COMPONENT DESIGN AND DEVELOPMENT
GROUP 73

INTEGRATED CIRCUIT FACILITY

The Integrated Circuit Facility has continued to make progress in materials handling, and many basic process techniques that are critical to our applications schedule are now well developed. However, combinations of different materials are required in many of the electronic disciplines that we serve, and it is necessary to establish the success of these basic process techniques in all of the material combinations.

A description of our current research, development and application program will indicate the nature and extent of the materials and processes that are under investigation or being applied.

Developmental work on the beam-lead substrate assembly concept has led to the selection of two very promising metalization systems for the beam leads and interconnections on the beam-lead substrate. These metallurgies are filament evaporated Cr/Pt with electroplated gold, and electron-beam evaporated Mo/Au with electroplated gold. Both of these metalizations resulted in excellent adhesion and good bondability. With the delivery of a two-cathode sputter-sputter etch module – now on order – a program will be initiated to evaluate the Cr/Pt and Mo/Au metalizations when both layers are sputtered. Research has also been initiated on the difficulties of thermocompression bonding the metallurgically reacted side of beam-leads to the pads on monolithic chips.

Work has continued on the problem of depositing and etching an isolation layer and a final metalization layer on single, monolithic chips. Photoresist techniques have been perfected to the point where adequate definition can be routinely achieved. The problems of depositing a pinhole-free SiO_2 layer and etching vias in the SiO_2 without disturbing the manufacturer's top metalization layer are currently being attacked.

The work on high resolution pattern definition and etching techniques has progressed well. Interdigital electrode transducers involving 1-micron fingers have been fabricated using refined optical-photoresist techniques. Etching is now done on a routine basis by reverse RF sputtering, especially where high resolution or edge definition is required.

RF sputter etching has also been used successfully in precision machining of troughs in silicon substrates in connection with a surface wave amplifier. Relief structures on other optically polished substrates have been similarly produced.

RF sputtering has permitted deposition of thin films when other methods were inadequate. Nickel for magnetic studies as well as tin and lead for superconductivity studies are examples. Films of SiO_2 are deposited routinely on a wide variety of substrates. Studies elsewhere indicate that sputtered SiO_2 is a close approximation in physical characteristics to the thermal oxide. Studies here indicate so far that this is the case.

In the development of very high (submicron) resolution the electron beam of a scanning electron microscope at M.I.T. has been used in studies of resist sensitivity and line resolution. Some special electron sensitive resists have been prepared and will be evaluated. The electron

beam method of pattern definition promises an order of magnitude improvement in resolution. In combination with sputter etching, it should lead to a new submieron technology.

The semiconductor section has undertaken as a first task the development of special Impatt diodes for the phased array radar program. Several groups are participating in the determination of the diode specifications and fabrication details. The semiconductor section is also continuing to support other sections in the Integrated Circuit Facility in Varactor and Impatt diode chip assembly methods, particularly for beam lead substrate structures.

A review of current applications indicates that a reasonably good balance exists between applied device fabrication, large circuit assemblies and material development. In some cases the materials research is being applied in support of fundamental studies of superconductors, advanced microwave networks and surface wave elements. In addition, there is a considerable growth in requests for hybrid and multichip circuit assemblies for various Laboratory systems.

Effort in computer-aided layout and mask making has resulted in a system of routines which allows the generation of a mask layout on the time-sharing system, using the 2250 and SC4020 displays. A punched paper tape is produced which drives a D. W. Mann Company pattern generator to create the mask. These programs were written in a manner which makes it possible for a nonprogrammer to use them with an absolute minimum of difficulty, and they are being distributed to other groups within the Laboratory.

The double precision version of the CIRCUS program has been completed, and while it has not yet been fully tested, it is showing significantly greater accuracy and speed than the single precision version. It is expected that many problems which could not be handled by the single precision version will now be solvable.

In order to facilitate the work above, an editing supervisor has been written making use of in-core file manipulating routines written by D. Evans of Group 63. This editor is more flexible and powerful than the standard CMS editor, and is available to others within the Laboratory. The in-core file manipulating routines are also a key part of the mask layout programs described above.

CONTROL SYSTEMS
GROUP 76

The laser radar mount was installed at the Firepond Infrared Research Facility. Wiring to interconnect the mount with other components of the control system was completed. Satisfactory closed loop performance of the rate and position loops was demonstrated, and digital equipment for reading information into and out of the general purpose computer was exercised. Group 76 furnished mount power drives, control consoles, computer interface logic, displays, and the equipment necessary to exchange pointing information between Firepond and the Haystack-Millstone complex. Interconnection between the laser radar and the cold tracker mount, through the computer, was also provided.

SOLID STATE
DIVISION 8

INTRODUCTION

This section summarizes the work of Division 8 from 1 November 1968 through 31 January 1969. A more detailed presentation is covered by the Solid State Research Project for the same period.

A. L. McWhorter
Head, Division 8

P. E. Tannenwald
Associate Head

DIVISION 8 REPORTS ON GENERAL RESEARCH

15 November 1968 through 15 February 1969

PUBLISHED REPORTS

Journal Articles*

JA No.			
3210	Si-Te System: Partial Pressures of Te_2 and SiTe and Thermodynamic Properties from Optical Density of the Vapor Phase	R. F. Brebrick	J. Chem. Phys. 49, 2584 (1968)
3267	Spherical Model as the Limit of Infinite Spin Dimensionality	H. E. Stanley	Phys. Rev. 176, 718 (1968)
3274	Magnetic Resonance	R. Weber	Chapter 7, Magnetism and Magnetic Materials – 1968 Digest, H. Chang and T. R. McGuire, eds. (Academic Press, New York, 1968)
3284	Nonmetals	N. Menyuk	
3296	Photoconductivity in Single-Crystal $Pb_{1-x}Sn_xTe$	I. Melngailis T. C. Harman	Appl. Phys. Letters 13, 180 (1968)
3328	Polymorphism in Silver Telluride at High Pressures and Temperatures	M. D. Banus M. C. Finn	J. Electrochem. Soc. 116, 91 (1969)
3347	Exchange Interactions and Raman Scattering from Spin Excitations in $RbNiF_3$	S. R. Chinn H. J. Zeiger	Phys. Rev. Letters 21, 1589 (1968)
3353	$LnCrTeO_6$ – A New Series of Compounds Based on the $PbSb_2O_6$ Structure	H. M. Kasper	Materials Research Bull. 4, 33 (1969)
MS-2221	Influence of the Molecular Interaction on the AC Kerr Effect: Possibility of a Field-Induced Phase Transition	J. Hanus	IEEE J. Quant. Electron. QE-4, 753 (1968)

* Reprints available.

UNPUBLISHED REPORTS

Journal Articles

JA No.			
3301	Effective Mass Theory for Polarons in External Fields	D.M. Larsen	Accepted by Phys. Rev.
3304	Self-Modulation, Self-Steepening and Spectral Development of Light in Small Scale Trapped Filaments	T.K. Gustafson* J-P. Taran* H.A. Haus* J.R. Lifsitz* P.L. Kelley	Accepted by Phys. Rev.
3308	Conditions for Microwave Radiation from Excited OH Λ-Doublet States	M.M. Litvak B. Zuckerman* D.F. Dickinson*	Accepted by Astrophys. J.
3317A	Fermi Surface and Optical Properties of Copper	G.F. Dresselhaus	Accepted by Solid State Commun.
3320	Single Crystal Lead-Tin Chalcogenides	I. Melngailis T.C. Harman	Accepted as chapter in Semiconductors and Semimetals, Vol. 7 (Academic Press, New York)
3335	A Transport Equation for Interacting Fermions in Random Scattering Centers. I. A Quasiparticle Description in the Macroscopic and Low Temperature Limit	J.L. Sigel P.N. Argyres	Accepted by Phys. Rev.
3340	Infrared Pumping of Interstellar OH	M.M. Litvak	Accepted by Astrophys. J.
3346	A New Series of Rare Earth Garnets $Ln_3^{+3}M_2Li^{+1}O_{12}$(M = Te, W)	H.M. Kasper	Accepted by Inorg. Chem.
3365	Photoluminescence of Metals	A. Mooradian	Accepted by Phys. Rev. Letters
3386	Transient and Steady State Thermal Self-Focusing	R.L. Carman* A. Mooradian P.L. Kelley A. Tufts	Accepted by Appl. Phys. Letters
3387	Infrared Transmission, Magnetic Birefringence and Faraday Rotation in EuO	J.O. Dimmock C.E. Hurwitz T.B. Reed	Accepted by Appl. Phys. Letters
3394	Far Infrared and Submillimeter Impact Ionization Modulator	I. Melngailis P.E. Tannenwald	Accepted by Proc. IEEE (Letters)
3411	International Conference on Silicon Carbide (A Conference Report)	J.R. O'Connor	Accepted by J. Crystal Growth

* Author not at Lincoln Laboratory.

Meeting Speeches*

MS No.			
2316A	A Phase Diagram for Electrons in Solids	J.B. Goodenough	Seminar, IBM Watson Research Center, Yorktown Heights, New York, 12 December 1968
2331A	Raman Scattering from Spin-Density Fluctuations in n-GaAs	D.C. Hamilton	Solid State Conference, University of California, 13-17 January 1969
2362A	The High-Pressure Forms of $CsNiF_3$	J.M. Longo J.A. Kafalas	Magnetism and Magnetic Materials Conference, New York, 18-21 November 1968
2374	Distant-Neighbor B-B Interactions in Cobalt Chromite	K. Dwight N. Menyuk	
2377	On the Critical Behavior of Quantum Mechanical Heisenberg Ferro- and Antiferromagnets	H.E. Stanley	
2378	Critical Indices for a System of Spins of Arbitrary Dimensionality Situated on a Lattice of Arbitrary Dimensionality	H.E. Stanley	
2380	Pressure Effect Measurements Using a Vibrating-Coil Magnetometer	N. Menyuk J.A. Kafalas K. Dwight J.B. Goodenough	
2384	Band Structure of Magnetic Semiconductors	D. Adler† J. Feinleib	
2385	Optical Studies and Band Structure of Cu-Ni Alloys	J. Feinleib W.J. Scouler J. Hanus	
2389	Raman Scattering by Magnetic Excitations in $RbNiF_3$	S.R. Chinn H.J. Zeiger	
2391	Ultrasonic Propagation in EuO	Y. Shapira† T.B. Reed	
2415A	Infrared Transmission, Magnetic Birefringence and Faraday Rotation in EuO	J.O. Dimmock C.E. Hurwitz T.B. Reed	
2387A	A New Thermal Hartree-Fock Approximation and Some Consequences	T.A. Kaplan P.N. Argyres	International Symposium on Atomic, Molecular, and Solid-State Theory and Quantum Biology, Sanibel Island, Florida, 13-18 January 1969
2470	Experimental Charge Density of Al	P.M. Raccah V.E. Henrich	

* Titles of Meeting Speeches are listed for information only. No copies are available for distribution.

† Author not at Lincoln Laboratory.

Reports

MS No.

MS No.			
2415	Infrared Transmission, Magnetic Birefringence and Faraday Rotation of EuO	J.O. Dimmock C.E. Hurwitz T.B. Rced	American Physical Society, Miami Beach, Florida, 25-27 November 1968
2420D	Light Scattering from Electrons in Solids	A. Mooradian	Seminar, Bell Telephone Laboratories, Holmdel, New Jerscy, 7 January 1969
2420E	Light Scattering from Semiconductors	A. Mooradian	Seminar, University of California, 17 January 1969
2425	Raman Scattering from InSb and lnAs Surfaces	K.W. Nill A. Mooradian	American Physical Society, San Diego, California, 18-20 December 1968
2458	The Maser Physics of Interstcllar OH	M.M. Litvak	
2426, 2426A	Laser Light Scattering Studies in Solids	A. Mooradian	Industrial Liaison Symposium, M.I.T., 18 December 1968; Seminar, Raytheon Company, Waltham, Massachusetts, 12 February 1969
2441	Interference Magnetoreflection Studies in InSb	P.W. Staecker* M.S. Dresselhaus S. Iwasa*	American Physical Society, New York, 3-6 February 1969
2443	A Transport Equation for Interacting Fermions in Random Scattering Centers. I. A Quasiparticle Description in the Macroscopic and Low Temperature Limit	J.L. Sigel P.N. Argyres	
2490	Effects of Electron-Phonon Interaction on Electronic Energy Levels	D.M. Larsen	
2445	The Fundamental Absorption Edge of Semiconductors	E.J. Johnson	Seminar, Boston College, 20 November 1968
2447	A New Look at the Fcrmi Surface	G.F. Dresselhaus	Colloquium, Yeshiva University, 18 Novcmber 1968
2450	Magnctic Critical Phenomena	H.E. Stanley	Colloquium, M.I.T., 22 November 1968
2451, 2451A, 2451B, 2451C	A New Look at the Fermi Surface	G.F. Dresselhaus	Seminar, Northeastcrn University, 26 November 1968; Seminar, National Magnet Laboratory, 11 Deccmber 1968; Seminar, Raytheon Company, Waltham, Massachusetts, 29 January 1969; Seminar, University of California, 20 January 1969

* Author not at Lincoln Laboratory.

MS No.			
2468	Finite Temperature Single-Determinant Theory	T. A. Kaplan	Seminar, Wesleyan University, 18 December 1968
2496	Pitfalls, Detours and Shortcuts on the Road to Single Crystal Growth	T. B. Reed	Electrochemical Society, Lexington, Massachusetts, 14 January 1969

SOLID STATE
DIVISION 8

I. SOLID STATE DEVICE RESEARCH

Guard-ringed GaAs Schottky barrier diodes have been fabricated which exhibit uniform avalanche photocurrent gains exceeding 100 with gain-bandwidth products over 50 GHz. The diodes consist of 5.3-mil diameter 100-Å thick semitransparent platinum Schottky barrier contacts electroplated on 2×10^{16} cm^{-3} n-type GaAs. The guard ring was formed by 400-keV proton radiation damage which generates an insulating region 4 μ thick. Operating at a gain of 100 the photoresponse was uniform across the active region of the diode to better than ±20 percent, the response speed was less than 0.3 nsec and the improvement in signal to noise over low bias conditions was 34 dB.

Efficient doping of GaAs has been observed using Se^+ ions implanted at 400 keV, and high quality n-p junctions have been obtained using this technique. These junctions, formed by implantations into p-type material, have low leakage currents and a sharp reverse breakdown voltage of 24 V. Van der Pauw measurements indicate that a substantial fraction of the implanted ions are electrically active. Differential C-V measurements on gold Schottky barriers plated on implanted n-type samples give a doping density curve which indicate that over half the implanted ions are electrically active.

Again using Se^+ ions implanted at 400 keV, n-p GaAs avalanche photodiodes have been fabricated which have photocurrent gains in excess of 300 when biased near reverse breakdown. As in the case of the Schottky barrier avalanche photodiodes, a guard ring of insulating GaAs was formed by 400-keV proton bombardment. The 4.8-mil diameter diodes have typical reverse leakage currents of about 3×10^{-10} A at 1 V, and sharp reverse breakdowns at 24 V. Again the photoresponse was found to be uniform over the entire region of the diode to better than ±20 percent at an average photocurrent gain of 100.

Low angle (2° to 4° between {111} planes) grain boundaries which can behave as back-to-back diodes have been observed in n-type ZnSe. It is postulated that acceptor type states exist at the tilt grain boundary produced by the lattice mismatch which can act as electron traps creating a double depletion region. The surface states are sufficiently dense that the grain boundary behaves like two Schottky barrier diodes connected back-to-back. Under reverse breakdown visible light is emitted at these boundaries but with rather low, $\sim 5 \times 10^{-5}$, quantum efficiencies.

Epitaxial layers of GaAs have been grown in an $AsCl_3$-Ga-hydrogen flow system with 77°K Hall mobilities up to 210,000 cm^2/V sec, a significant improvement over the best previously known material. The best sample had a peak mobility of 340,000 cm^2/V sec at 40°K and a total ionized impurity concentration of about 1×10^{14} cm^{-3} which is approximately a factor of five improvement over previously reported values.

The effects of light on the charge state of anodized InSb MOS devices have been further classified. Infrared radiation in the energy range between 0.23 and 1.2 eV penetrates into the InSb and is absorbed, creating electron-hole pairs with insufficient energy to escape into the oxide. Starting at about 1.2 eV some of the electrons photoexcited in the InSb escape and become trapped

in the oxide. At photon energies in excess of about 3 eV, electron-hole pairs are also generated in the oxide causing it to become photoconductive. By applying bias at these high photon energies the charge state of the oxide can be modified so that the surface of the n-type InSb can be swung from accumulation to depletion to inversion in a controlled fashion.

We have observed laser emission from diodes fabricated from the pseudo-binary alloy $Pb_{1-x}Sn_xSe$ in the composition range $0 \leqslant x \leqslant 0.279$ and have studied the composition and temperature dependence of the laser emission energy. For diodes fabricated from material with $x \geqslant 0.19$ the energy of the laser emission decreases as the temperature increases which is opposite to the situation in PbSe. This strongly supports the model in which the valence and conduction bands invert and exchange roles in the $Pb_{1-x}Sn_xSe$ alloy series as x is increased from 0 to 0.4.

We also have studied the magnetic field dependence of the laser emission energy in this alloy series in magnetic fields up to 50 kG. In the higher Sn content alloys with $x \geqslant 0.19$ the energy of the longest wavelength laser emission line decreases as the magnetic field is increased. This behavior is also opposite to the situation in PbSe and lends additional support to the band inversion model. This effect may also allow one to tune the laser emission to very long wavelengths using a magnetic field.

Interdiffusion in PbSe has been studied by diffusing excess Se into Pb-rich n-type PbSe and excess Pb into Se-rich p-type PbSe. The motion of the resultant p-n or n-p junction as a function of time and temperature is in essential agreement with a diffusion model which assumes that the interdiffusion coefficient has two values, D_p in Se-rich material and D_n in Pb-rich material with $D_p = 9D_n$.

II. MATERIALS RESEARCH

Transparent, resistance-heated furnaces have been constructed for vapor crystal growth or other applications at temperatures up to 1000° to 1100°C. Conventional insulation is replaced by a layer of gold, deposited on Pyrex, which is highly reflecting in the infrared but thin enough (about 400 Å) to transmit in the visible.

Single crystals of $RbNiF_3$ have been grown from the melt by lowering a graphite crucible containing the compound, protected by an argon atmosphere, through an RF induction coil. The apparatus is also designed for the growth of ABF_3 crystals which require an HF atmosphere.

Compounds of the $CsBF_3$ type (B = Mn, Fe, Co, Ni, Zn, Cd, Mg) exist in four related close-packed structures, which range from entirely hexagonal to entirely cubic (perovskite). The proportion of cubic close packing is found to increase with increasing size of the B-cation and with increasing hydrostatic pressure.

Optical absorption measurements have been used to determine the Te_2 partial pressure over condensed phases in the Bi-Te system as a function of composition and temperature. Solidus points for Bi_2Te_3 obtained from the pressure data are in good agreement with those calculated from Hall coefficient data by using the antistructure model for the stoichiometric defects.

Optical absorption measurements have been used to determine the partial pressures of Zn and Te over Zn-saturated and Te-saturated ZnTe, respectively, and to determine both pressures over ZnTe samples close to the congruently subliming composition. From the latter data, values of the equilibrium constant $p_{Zn}p_{Te_2}^{1/2}$ have been obtained for the range 960° to 1190°K.

Solidus curves for a number of semiconductor alloy systems have been calculated from the experimental liquidus curves by assuming that the deviations from ideality are comparable in the solid and liquid phases. For most of the systems, the calculated curves are in rather good agreement with the experimental solidus data, particularly for compositions not too close to the constituent with lower lattice constant.

X-ray scattering factors for aluminum have been obtained by means of absolute intensity measurements on cold-worked powder pellets. Except for the first two peaks, which are influenced by solid state effects, the data are in good agreement with the results of relativistic Hartree-Fock calculations for the free atom, but not with those based on Slater's approximation to the exchange operator.

A method had been developed for determining by electron microprobe analysis the four major components in $(Pb_{1-x}Sn_x)(Te_{1-y}Se_y)$ alloys. An iterative procedure is used to obtain the correction factor for each element needed to calculate the atom fraction of the element from its measured X-ray intensity.

III. PHYSICS OF SOLIDS

Previous oscillatory magnetoreflection results on bismuth-antimony alloys in the range of composition $0 \leqslant \%\,Sb \leqslant 15$ have been complemented by measurements of additional alloys. Our measurements indicate the motion of some of the energy bands in the alloys and permit an identification of the L-point energy bands involved in transitions in pure bismuth with those involved in pure antimony. The results suggest a pattern for the variation of the energy bands at the L- and T-points in the Brillouin zone for the bismuth-antimony-arsenic system which is consistent with all previous magnetoreflection data in these semimetals.

As part of a program for studying the band structure of the ferromagnetic semiconductor EuO, reflectance measurements have been carried out at photon energies between 1 and 11 eV at 300° and 77°K. Presently a Kramers-Kronig analysis is being performed in order to obtain the dielectric constant.

The 168 cm^{-1} ultraviolet-induced absorption line in AgBr, previously assigned to a 1s-2p transition of a bound polaron, has been examined in a magnetic field at liquid helium temperatures. A splitting, due to both the linear and quadratic Zeeman effect, has been observed.

A study has been initiated of electron tunneling through insulating films into PbSe with emphasis on the effects of the optic phonons. So far, the equipment has been checked out on GaAs; also preliminary measurements have been obtained in p-type PbSe.

The approach which was recently used to generalize the standard thermal Hartree-Fock approximation (STHFA) into a form, the thermal single determinant approximation (TSDA), for dealing more satisfactorily with entropy in the zero-temperature limit, has now been applied to a boson system.

Measurements have been carried out on the magnetic field dependence (2.5 to 23.5 kOe) of the nuclear resonance linewidth of Mn^{55} in the low anisotropy antiferromagnetic compounds $CsMnF_3$ and $RbMnF_3$ at 18° and 4.2°K. An interpretation of the linewidth behavior in terms of existing theories gives fair agreement except for an unexplained anomalous linewidth peak which is observed only in $RbMnF_3$.

The spin-space group concept, advanced by Brinkman and Elliott for analyzing the symmetry properties of spin waves in magnetic insulators where spin-orbit coupling effects are negligible for the ground state of the magnetic ion, can be extended to optical excitons arising from single-ion transitions between the ground state and an excited state where spin-orbit effects are negligible. This idea has been applied to the $^4A_2 \rightarrow {}^2E$ excitons in Cr_2O_3 to investigate the role of spin-orbit coupling in producing the small but nonzero measured transfer-of-excitation matrix elements between opposite spin sublattices.

Using Brillouin spectroscopy, the velocity and attenuation of 27- to 28-GHz longitudinal hypersonic waves in fused quartz have been measured between 80° and 600°K. The pronounced attenuation peak at ~130°K, also observed previously by ultrasonic measurements but attributed to a structural relaxation mechanism, can be explained by a simple anharmonic mechanism involving scattering of thermal phonons.

Using exchange parameters obtained from two magnon Raman scattering and other magnetic measurements in $RbNiF_3$, a classical BPW calculation of the Curie temperature of $RbNiF_3$ has been performed. The calculated value of T_c is 135°K, compared with a measured value of 139°K. In addition, good agreement is obtained between calculations of sublattice magnetization above T_c in a magnetic field, and values inferred from NMR measurements.

It can be shown that for a Maxwellian electron gas the cross section for light scattering from single particle electron excitations is proportional to the electron distribution function under the conditions that (a) the momentum change imparted to the electron is large compared to the Debye wave vector and (b) the electrons have an infinite relaxation time. Experimental measurements in GaAs have confirmed these theoretical results.

The effect on the nonlinear refractive index of molecular interaction between anisotropic molecules in liquids has been investigated. Under certain restrictive conditions the liquid can be driven into a new ordered phase, similar to a liquid crystal mesophase.

DOCUMENT CONTROL DATA – R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Lincoln Laboratory, M.I.T.	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP None

3. REPORT TITLE

General Research Quarterly Technical Summary Report

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Quarterly Technical Summary for 1 November 1968 through 31 January 1969

5. AUTHOR(S) *(Last name, first name, initial)*

Frick, Frederick C. Dodd, Stephen H. Weiss, Herbert G. McWhorter, Alan L.
Nedzel, V. Alexander Herlin, Melvin A. Hutzenlaub, John F. Tannenwald, Peter E.

6. REPORT DATE 15 February 1969	7a. TOTAL NO. OF PAGES 52	7b. NO. OF REFS 7
8a. CONTRACT OR GRANT NO. AF 19(628)-5167 b. PROJECT NO. 649L c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) General Research QTS for 15 February 1969 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)* ESD-TR-69-4	

10. AVAILABILITY/LIMITATION NOTICES

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES None	12. SPONSORING MILITARY ACTIVITY Air Force Systems Command, USAF

13. ABSTRACT

This Quarterly Technical Summary covers the period from 1 November 1968 through 31 January 1969. It consolidates the reports of Division 2 (Data Systems), Division 3 (Radio Physics), Division 4 (Radar), Division 7 (Engineering), and Division 8 (Solid State) on the General Research Program at Lincoln Laboratory.

14. KEY WORDS

data systems
digital computers
computer components
psychology
control research
radio physics
space surveillance
radar
microwave equipment
mechanical and structural engineering
solid state physics